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Authentic science in education: Studies in course-based research at the United States Military Academy

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AUTHENTIC SCIENCE IN EDUCATION: STUDIES IN COURSE-BASED RESEARCH AT THE UNITED STATES MILITARY ACADEMY

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ABSTRACT

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This dissertation consists of two studies at the United States Military Academy. Both studies involve the use of Course-based Undergraduate Research Experiences (CUREs). These experiences give students the ability to engage in undergraduate research at an early point in their academic career by replacing traditional laboratory activities with semester-long research projects. Both studies show an implementation of this type of instruction from the Center for Authentic Science Practice in Education (CASPiE). Study 1 shows the specific method of implementation at the military academy and explores learning-based outcomes. Primarily the outcome of critical thinking is demonstrated. Critical thinking is a construct that many curriculum developers and instructors want to foster within their students but often lack clear definitions or evaluation plans. This study gives a definition of critical thinking and an outcome of a critical thinking test. Significant gains in critical thinking are observed by students participating in the CURE as well as significant gains in three affective factors (Interest in Science/Chemistry, Authenticity, Perceived Learning). The gains in critical thinking are then further statistically linked to students' perceptions of how authentically they saw

the research in the course. If they felt that the course was demonstrating more authentic science practices, they gained significantly more in their critical thinking scores.

The second study in this dissertation adds an additional transfer focus to the instructional materials that the CURE was meant to support. The treatment group in this study received instruction that was framed expansively. The expansively framed instruction showed students ways that the material was applicable outside of the course. The assessments and instructional materials of this study were transfer assessments with contrasting cases. Instances of negative or “overzealous transfer” were also reported. Findings suggest that students in the transfer-focused treatment condition display a deeper understanding of the inner workings of the Gas Chromatograph more so than the control group which focused on output of the instrument only. Analyses of instances of negative transfer or overzealous transfer in this study show a reduction in instances for the treatment groups. This can be theoretically attributed to the use of Inventing with Contrasting Cases for individuals in the treatment group as this is postulated to reduce instances of negative transfer. Future work in this area is suggested to incorporate studies with control-treatment comparisons across groups of larger populations to tease out significant differences of means on transfer assessments. Further, the transfer assessments used need to be comparable in level of difficulty as the ones in this study appeared to differ.

CHAPTER 1. INTRODUCTION

1.1 Introduction

At the outset of my graduate education, I joined a research group that performed synthetic organic chemistry research. This group worked tirelessly to find new mechanisms and synthesize molecules that had yet to be formed before (or synthesize them in novel methods) in the laboratory. The reason that I engaged in this type of research is that up to this point, I had not engaged in this type of scientific practice. I was entering a graduate program and had not done research around the types of things to which I had essentially committed my professional life. This disconnect fascinated me as continued through the program and realized over time that this was not the type of work that I wanted to do for rest of my professional life. Disconnects such as these occur to students for a variety of reasons. Many students do not have opportunity or access to undergraduate research. Others engage in undergraduate research but do not perform meaningful tasks as undergraduate research experiences are largely unregulated. Undergraduate research does not traditionally include a component that shows learning gains or benchmarks of research experiences. This motivated me to explore course-based research as a research area in my graduate program. This is the primary focus of this dissertation

Contained in this dissertation are two studies that explore educational outcomes within courses that contain Course-based Undergraduate Research Experiences (CUREs). CUREs set the backdrop for studies that first look at what gains are achieved by students within the course (study 1), and then how specific methods within the course can impact the future application of material learned within it (study 2). Together these studies strengthen the CURE literature as they highlight beneficial components of implementation.

Study 1 contains an examination of one type of CURE from the Center for Authentic Science Practice in Education (CASPiE). The CASPiE method is outlined as well as the participants who are cadets from the United States Military Academy (USMA). This military academy has proven to be a great environment in which to do educational research studies. USMA has been effective as a testbed for educational research due to their unique instructional strategies and curricular control. USMA has also shown a willingness to innovate as the faculty have implemented these novel educational methods in a very short time frame. The CASPiE method began with 87 students in study 1 and now impacts nearly over 150 each semester. Study 1 investigates how participation in this CURE impacted critical thinking over a treatment semester. Further, results in critical thinking were shown statistically to be dependent upon the degree to which students saw the laboratory experiences as authentic. If students saw the experiences to be more authentic, they had significantly higher critical thinking scores at the end of the semester.

The findings from study 1 were very interesting to curriculum developers at both Purdue and USMA. The gains from participation in the program were evident and the resultant question was about what happens during instruction and after the semester with the course content. This led to study 2 which examines the instructional methods and applicability of the course material. USMA as an institution is focused on preparing cadets for their future military careers and creating “life-long learners” out of their graduates. Therefore, it seemed appropriate to study the degree to which material is transferred after instruction from a unique academic experience such as a CURE.

Study 2 examined the relationship between expansive framing and transfer within a CURE. Expansive framing is instruction that is framed in such a way that students directly see the application of the material that they are being instructed. The instructor directly informs students about the instances in which the material is useful and applicable in the future after the course (Engle et al., 2012). This directly connects students to real-world applications that they may encounter in the future where the course material is relevant. In the case of the expansive framing condition, expansive framing is meant to encourage transferal of material among the treatment group. Alongside of these expected impacts, Inventing with Contrasting Cases was added to this condition with the goal of mitigating instances of negative transfer. Their performance on transfer assessments were then compared in a control-treatment designed experiment. Answers to a question about Gas Chromatography were compared between control and treatment groups. Qualitatively, it appeared that students in the treatment group showed a deeper understanding of the material as their answers suggested more detailed examples of the workings of the instrument. This, however, was only observed in the top-performing students. The same results were not observed in lower performing students.

One major criticism of transfer research is that students tend to transfer material mapping it onto situations that are not appropriate. This is known as overzealous transfer. Overzealous transfer is said to be mitigated using Inventing with Contrasting Cases (ICC) (Schwartz et al., 2012). A classic example of ICC is one in which a picture of a house is presented. There are many possible issues with the picture of a house, yet it is not clear the content that is trying to be communicated. This is until a second picture is presented in which the chimney is above the roof of the house. It is then clear that the chimney was the problem and the target of instruction (Schwartz et al., 2016). ICC was used for study 2 and instances of overzealous transfer were less than half than that of the control group. This adds to literature stating ICC is a way of reducing overzealous transfer.

These studies together display that CUREs are a great way to give students the experiences that I lacked at the outset of my graduate career. While giving students these authentic research experiences, they increase critical thinking and foster an environment where material can be instructed in an expansive way producing deeper understanding. The following two studies go into further detail about the methods, analyses, results and implications of these two studies as well as where the research program can continue to investigate these instructional methods.

CHAPTER 2. IMPROVING CRITICAL THINKING VIA AUTHENTICITY: THE CASPIE RESEARCH EXPERIENCE IN A MILITARY ACADEMY CHEMISTRY COURSE

2.1 Abstract

Course-based undergraduate research experiences (CUREs) can introduce many students to authentic research activities in a cost-effective manner. Past studies have shown that students who participated in CUREs report greater interest in chemistry, better data collection and analysis skills, and enhanced scientific reasoning compared to traditional laboratory activities. Though self-reports are informative, performance measures are needed to evaluate CURE effectiveness objectively. The present study examines whether a CURE implementation at the United States Military Academy (by the Center for Authentic Science Practice in Education [CASPiE]) affects students' self-reported perceptions or critical thinking test scores. Students reported significant increases in their perceptions of learning through the laboratory, authentic scientific laboratory practices and interest in chemistry when compared to previous chemistry courses with traditional laboratory activities. Results also showed a significant increase in critical thinking scores, moderated by student perception of the authenticity of the laboratory activities.

2.2 Introduction

CHEMISTRY IS AN EXPERIMENTAL SCIENCE that encompasses both theoretical and practical training within its instruction. As practical skills are taught primarily in laboratory courses, most college-level chemistry courses include a significant laboratory component. (Abraham et al., 1997). Unlike traditional laboratory activities that ask students to verify known chemistry relations, researchers have proposed having students conduct authentic research through course-based undergraduate research experiences (CUREs). These experiences afford students the opportunity to participate in a real research project throughout the semester. Students plan and execute experiments, collect data, and report results as a part of the laboratory course component. Vital outcomes of chemistry courses include teaching students skills that are relevant for the chemistry field, including critical thinking – the focal point of many recent chemical education studies (Bruehl et al., 2015; Carmel & Yezierski, 2013; Uzuntiryaki-Kondakci & Capa-Aydin, 2013) and a target goal in academic and national educational standards (Olson & Loucks-Horsley, 2000; Osborne, 2014). Critical thinking is defined as creative thinking, problem solving, data interpretation/analysis, and communication (Stein et al., 2007).

In this study, we test whether course-based undergraduate research experiences (CUREs) within a chemistry context increase students' critical thinking skills for undergraduate students in a military academy. We further investigate possible reasons for those increases. We employ measures that probe students' ability to think critically before and after a CURE implementation at the United States Military Academy

(USMA). Their performance on these measures were then added to self-report survey questionnaires to examine causal interpretability of changes.

As a result of this recent emphasis on improving critical thinking, curriculum developers have started altering goals of the laboratory component of many science curricula. These interventions aiming to improve critical thinking have focused on students' collaborative efforts and activities beyond traditional lectures. Gupta et al. (2015) scored laboratory reports to show that the Science Writing Heuristic improved students' critical thinking skills. Recent studies have also shown that learning interventions (e.g., active learning, Kim et al., 2013; Peer-Led Team Learning, Quitadamo et al., 2009) can improve critical thinking. When students face authentic situations that require collaboration to achieve project goals, they often interact with course materials critically. This is the foundation of this study. Students were given authentic research tasks to complete in teams that incorporated hypothesis development, data collection and presentation of findings. These goals presented a unique opportunity to examine whether authentic practices in the science laboratory affect students' critical thinking.

As a supplement to course lectures, laboratory activities often confirm known hypotheses by repeating standard experiments. These are verification laboratory activities and contrast with authentic research activities in which the outcome is unknown. As students follow step-by-step instructions during verification laboratory activities, these activities do not prepare students well for future research endeavors or jobs (Szteinberg & Weaver, 2013).

In many universities, research opportunities are restricted to a few students within their final semesters of undergraduate education, as reported by Canaria *et* al. (2012 p. 1372):

"It is not feasible to require undergraduate research as part of the degree program at a large university. The high student-to- faculty ratio makes it impossible to support all of these students in a research project."

CUREs, however, enable many students to participate in authentic, research activities (Auchincloss et al., 2014). These experiences vary in nature but often include semester-long, authentic research experiences that sometimes give students the ability to be co-authors on research manuscripts (Gasper et al., 2012). Students participating in these experiences form groups and learn research techniques. They advance the research project by collecting data and analyzing them to complete a final project or presentation. These types of curricula offer authentic research experiences to students in entry-level classes. CUREs are less costly, larger-scale means of providing students with research experiences, compared to the traditional undergraduate research internship (which often requires many more research faculty to supervise the same number of students).

With suitable preparation, Wolkow et al. (2014) found that CUREs can be implemented successfully at both two-year and four-year institutions to yield positive student experiences. For example, United States Air Force Academy cadets in a CURE produced data for researchers and co-authored publications (Snellman et al., 2006).

CUREs have increased students' self-reported interest in chemistry, improved their data collection and analysis skills, and enhanced their scientific reasoning. These represent important components of critical thinking within science courses (Wood &

Gentile, 2003; DebBurman, 2002; as reported by Gasper & Gardner, 2013; Weaver, 2008). Though successes involving CUREs have been reported, a meta-analysis of 60 studies of undergraduate research experiences by Linn et al. (2015) showed that most studies relied on students' self-reports. Linn and colleagues highlighted the need for systematic as well as iterative studies. These studies must contain multiple indicators of success (echoed by Brownell and Kloser, 2015). In their framework for CURE evaluation, Brownell and Kloser (2015) advocate measurement of affective outcomes alongside measurements that contain compentcies in science. This study addresses this issue by providing both self-report analyses and objective critical thinking data to support the impact of CUREs on critical thinking.

The Center for Authentic Science Practice in Education (CASPiE) was developed with the goal of streamlining the procedure of giving students authentic scientific research experiences at universities. CASPiE is "a multi-institutional collaborative project that aims at providing course-embedded authentic research experiences for undergraduate students during their early years in college, specifically during their general and organic chemistry courses" (Szteinberg & Weaver, 2013 p. 24). After a series of skill-building modules to teach skills relevant to the research, students form research groups in the classroom, approach data with different hypotheses, and present their results at the end of the semester.

Early CASPiE studies showed several benefits for students. For example, this teaching model challenges students to design their own experiments (Weaver et al, 2006). Also, the CASPiE experience can increase students' connections between science and everyday life and affect their future career choices (Weaver et al., 2008). Furthermore, studies of a CASPiE module on antioxidant capacities in foods increased the sophistication of students' views on the nature of science (Hoch et al., 2009; Russell & Weaver, 2011). Specifically, students gained a better understanding of the meaning of experiments and scientific theories.

Another study showed that student interest in science and understanding of research methods both increased after participating in CASPiE (Scantlebury & Woodruff, 2011). This study also showed that CASPiE particularly engaged female students and students from minority groups. In a three-year study, Szteinberg & Weaver (2013) showed that students who participated in CASPiE had a greater sense of accomplishment and greater perceived responsibility than before. They also remembered the main ideas of the laboratory work after one year. Furthermore, Pilarz (2013) showed that CASPiE helped high school students develop a stronger, scientific research community, in which they communicated and worked with one another and with their teachers. Lastly, Gasper and Gardner (2013) showed that a version of CASPiE with a biological focus in an undergraduate course helped increase students' critical thinking.

2.3 Study Overview

This study examines the relationship between participation in the CURE chemistry course-based research experience and critical thinking. Additionally, the present study examines the impacts of the CURE on perceptions of (a) learning through the laboratory, (b) authenticity of scientific laboratory practices, and (c) interest in the chemistry/science of the course, when compared to previous chemistry courses with traditional laboratory activities.

Research Questions:

1. What is the impact of the CURE participation on critical thinking?
2. What is the impact of CURE participation on perceptions of (a) learning through the laboratory, (b) authenticity of scientific lab practices, and (c) interest in the chemistry/science of the course when compared to a traditional chemistry course?

Hypothesis 1: Participation in the CURE increases critical thinking.

Hypothesis 2: Compared to their previous course, CURE students increase their:

- Perceptions of learning through the laboratory
- Perceptions of authenticity in scientific lab practices
- Interest in chemistry/science

This study was performed at the United States Military Academy (USMA) at West Point, NY. USMA students, known as cadets, are committed to five years of active duty service as Army officers upon graduation. Cadets at West Point currently are required to take (or validate) a full year of General Chemistry during their freshman year. Despite a typical admittance of roughly 1200 cadets per year, all classes at West Point have a class size of 19 cadets per instructor for a core course such as General Chemistry, and even fewer cadets normally attend upper level courses. Their "Thayer Method" teaching style resembles the Socratic method; lecture format is not permitted (Shell, 2002). The faculty at West Point is approximately one-third civilian and two-thirds military. Civilian faculty are PhD holders comparable to faculty at any major undergraduate institution, whereas the majority of military faculty serve at West Point for three years after earning a Master's degree, and in some cases officers serve a second three-year tour after earning a PhD. When not in graduate school or teaching at West Point, these officers are assigned to traditional military positions (infantry, transportation, combat engineers, etc.). Hence, these officers are familiar with the needs of the US modern fighting force, on which they can capitalize to teach cadets in a scientific field.

The participants in this study were 86 cadets enrolled in six sections of Advanced General Chemistry courses, all of which include laboratory work. These cadets scored high on a Chemistry exam administered during their first week at the Academy. Cadets either meet for an 80-minute class or attend a 2-hour lab every other day. The Advanced General Chemistry course sequence covers nearly the same material as the regular General Chemistry course sequence, but the material is compressed into fewer lessons to allow for trips or more extensive laboratory experiences. During the 2014 academic year, cadets in the Advanced General Chemistry course (CHEM 152) participated in the CURE during the second semester, which replaced several traditional laboratory activities and resulted in some compression of other course objectives into fewer lessons. No content was removed from the course.

2.4 Method

Eighty-six undergraduate cadets from USMA participated in this study and enrolled in the advanced general chemistry course (CHEM 151/152). They were 83% male and 17% female between the ages of 17 and 22 years (mean = 18.7).

The experiment contains a within-subjects design testing pre/post differences. The within-subjects comparisons come from pre/post differences only associated with those students in the CASPiE program. These variables include the affective responses from a self-report survey. Scores on the critical thinking test were compared across the treatment semester for changes. Regression models then examined whether their perceptions of the CASPiE program accounted for the differences in pre- and post-test scores. Participants in the study were afforded the opportunity to opt-out of data collection. Protocols were approved through the Human Subjects Research Protection Program at USMA. Though the authors of this manuscript include the course instructors, de-identified data were collected and analyzed by external collaborators.

In order to link cadet work with important on-going research, we asked these cadets to conduct research on a relevant military problem that may directly affect them upon graduation from West Point. The Waste-to-Energy research project selected for this CASPiE experience sought to tackle simultaneously two major challenges faced by the fighting force in the modern Army: (1) disposal of waste at Contingency Bases (CBs) or Forward Operating Bases (FOBs) and (2) provision of energy to generators used to power these locations. On a daily basis, a typical Army base in an undeveloped area can consume a staggering amount of fuel and water as well as generate over 1,000 lbs. of solid waste. This diverts significant manpower from mission operations to manage the delivery and security of these resources. Fuel costs are high while deployed, and delivering fuel to the end user requires overcoming several logistical and security challenges. In addition to fuel requirements, the predominance of open burning of solid wastes as an expedient disposal method has increased soldiers' health risks. Specifically, these soldiers might inhale smoke and particulates from incomplete combustion of a wide variety of wastes. While the Department of Defense has tried to limit the hazardous constituents being burned and has fielded small incinerators at some locations, the problem remains.

One proposal to alleviate these important problems is a gasification-based waste-to-energy technology, suitable for use in a CB. Gasifying solid wastes is much less complicated than liquid wastes. However, gasifiers currently have a hard time dealing with mixed wastes. While gasifier syngas products could be transformed into liquid fuels, the overall intent of this research project is to design a rotary kiln, waste-to-energy, gasification system that will directly burn the syngas for fuel and:

- be easily deployable
- accepts many different types of wastes without pre-preparation
- provide a syngas that will fuel a standard Army diesel generator at a net-positive energy balance, displacing a large fraction of fuel use.

A rotary kiln design was selected to allow for gasification of a wide variety of materials to simultaneously alleviate the challenges posed by waste and provide fuel on CBs (Cosper, 2014). A rotary kiln gasifier operates on the most straightforward possible mode of gasification: direct flaming pyrolysis. Solid and potentially liquid wastes are thermally converted to a flammable gas at temperatures above 800 °C to prevent char residue; inorganic ash is the only byproduct. The overall goal of the research project is to better understand how changes in the waste stream affect syngas characterization. Because the overall gasification project occurs at multiple locations, the cadets were assigned to focus on narrower aspects of the overall project. Cadets focused on the gas cleaning process, including selection of the scrubbing agent (liquid solvent or solid phase material).

The evaluative procedures for the CASPiE program consisted of a survey developed by the researchers that assessed student attitudes towards learning chemistry in the laboratory classes (Wink & Weaver, 2008). Students are asked to respond on a 5-point scale of agreement to a series of statements about their beliefs regarding chemistry and the course experience. The original study by Wink and Weaver (2008) measured self-reported gains when compared to the previous chemistry class that the student had taken. The survey was administered at the beginning and end of the treatment semester via an online survey distribution tool. Students received 10 points of extra credit for completing the survey each time and were given the option to complete an alternative activity for extra credit in lieu of participating in the evaluation.

The Critical-thinking Assessment Test (CAT) developed by Tennessee Technological University was used to show critical thinking changes across the entire academic year (Stein et al, 2007). The CURE implementation occurred only in the second semester. The test takes approximately 45 minutes (though students were given up to 60 minutes if needed) and contains 15 open-ended questions that put students in various scenarios to probe their critical thinking. The CAT was administered at the beginning of the spring semester (January 2014) and at the end of the second semester (May 2014). Tests were scored anonymously by a panel of instructors with an agreed upon rubric for each question. A person directly trained by the test developers led the scoring of the tests. Scores were then sent back to the developers to confirm that the scoring was valid and reliable. Scores were then tabulated and sent to the authors for further data analyses. Student participation in the CAT was completely voluntary, and they received no compensation. Seventy-seven of the total 86 students participated in all implementations of the self-report and CAT surveys.

At the outset of the course (six weeks before the CASPiE modules), cadets were introduced to the research project and three possible research topics. Each instructor gave a concise presentation corresponding to his or her research area. A further description of each component of the course is described in the supporting materials of this manuscript (see Appendix). These presentations gave cadets a background of the science involved within the research, the overall plan of the project, and some of the techniques involved. Two weeks before the beginning of the modules, cadets were shown the overview slides a second time and asked to select the set of modules that they would like to pursue. Next, the instructor of their selected module gave them introductory reading assignments. The three major components roughly corresponded to the three academic majors offered in the Department of Chemistry and Life Science at West Point: Chemistry (Analytical Chemistry), Life Sciences (Toxicology), and Chemical Engineering. This had the additional benefit of reducing the cadet-to-instructor ratio to an average of six cadets per instructor, rather than the normal 18:1 ratio typical at West Point. The smaller cadet-to-instructor ratio facilitated instructor-student interaction. Within each component of the course, cadets were organized into groups of 2-3. Each group worked together to formulate a unique hypothesis and collect data. Finally, each group presented a poster of their work at the end of the semester.

2.5 Data Analyses

Confirmatory factor analyses (CFA) of the student responses to three sets of three survey questions self-report data yielded the corresponding three factors (see Table 1). A gender variable was added to each CFA specification for sufficient degrees of freedom. Factor models were assessed for global model-data fit by for goodness-of-fit statistics. Good model fit is indicated by a failure to reject the null hypothesis as measured by fit indices. Good model fit is indicated by a root mean squared error approximation value less than 0.10, a Tucker-Lewis Index greater than 0.95, and a standardized root mean residual less than 0.08 (Hu & Bentler, 2009). STATA v14 Statistical Software was used to test the fit of the factor models in this study (StataCorp, 2015). This analysis was followed by a paired samples t-test of the weighted mean sum scores (DiStefano et al., 2009) from each standardized factor loading.

Linear regression tests whether several explanatory variables are simultaneously correlated with the target outcome of total critical thinking score. Specifically, it tests the hypothesis that each explanatory variable's regression coefficient differs from zero at a 95% confidence level (all else being equal). Pre-post gains for CAT and self-report surveys were analyzed by paired samples t-tests of significance at a 95% confidence level. A correlational matrix of these variables is presented in the supplementary material of this manuscript (see Appendix, Table A1). Effect sizes of these gains were assessed by Cohen's d.

Table 2.1 Description of Items in Self-Report Survey

Factor	Survey Item
Interest in Chemistry/Science	*The lab experience made me more interested in chemistry.* *The lab experience made me more interested in science.* *The lab experience made me more interested in a science career.*
Authentic Scientific Lab Practices	*The lab experiences were very similar to real research.* *The lab experiences made me realize I could do science research in a real science laboratory (for instance, at a college or with a pharmaceutical company).* *The lab experiments presented real science to students, similar to what scientists do in real research labs.*
Perceptions of Learning through Laboratory	*I better understood the ideas of chemistry, in general, as a result of completing the experiments.* *I believe I could accurately explain a chemistry experiment from the course to other student.* *I believe I could accurately explain a chemistry experiment from the course (including the significance of the results) to my instructors.*

2.6 Results

The results of the factor analyses were similar to those in the original CASPiE report (Wink & Weaver, 2008). Table 2 displays the emergent factors as well as their standardized root mean square residuals, root mean squared error approximations, Tucker-Lewis indices and global chi-squared values.

Differences in factor scores on the pre- and post-surveys showed significant increases in perceived authentic scientific laboratory practices, perceptions of learning through the laboratory, and interest in chemistry/science changes. These results suggest that after CURE participation, students perceived improvements in all three dimensions. A significant difference in perceived authenticity shows that students felt that the CURE was more authentic than previous laboratory courses. Gains in interest in chemistry shows that CURE participants feel as though they can pursue further education or work in chemistry after the academy.

Students also felt that they learned significantly more through the CURE than through earlier laboratory courses. Students scored higher on the CAT post-test after CASPiE participation than on the CAT pre-test (see Table 3, model 1). This supports the hypothesis that course-based research experiences can improve students' critical thinking abilities. Further regression analyses explore other factors (specifically those related to demographic data and the self-report survey) and their relationship with this change across the treatment semester.

The next series of models investigates whether several explanatory variables might account for the higher CAT score among CURE participants. While authenticity alone was not significant (Table 3, Model 2), its interaction with participation in the CURE was significant (Table 3, Model 3). As the survey asked students about their recent experience (previous semester), this result shows that authenticity significantly predicts CAT score after participating in the CURE program. Students who viewed the program as more authentic significantly gained in critical thinking after participating in the CURE program. Model 4 shows that this result is robust; after adding Gender and Ethnicity variables, the interaction between CURE participation and the May implementation of the CAT remains the only significant predictor.

Parallel regression models were run for both perceived learning and interest in science. Models 2-4 were run for each of the two factors to determine if the change in CAT score could be also attributed to changes in students' perception of learning or their interest in pursuing further education/work within the chemistry/scientific field. Models 2-4 showed no significant predictors of CAT score when incorporating interest in chemistry/science or perceived learning. The only series of models that statistically predicted changes in CAT score was the authenticity-based regression models displayed in Table 3. Results from the regression of interest in chemistry/science models as well as the regression of the perceived learning models can be found in the supplementary materials.

Table 2.2 Resulting Factor Loadings and Pre/Post Changes

Weighted Mean-Sum Scores Analysis				**Confirmatory Factor Analysis**			
Variable	Pre-mean	Post-mean	Mean-difference	SRMR	TLI	RMSEA	Chi-squared p-value
Perceptions of Learning through Laboratory	11.52	12.34	+0.821***	0.008	1.004	0.102	0.069
Interest in Chemistry/Science	11.24	12.40	+1.15***	0.012	1.005	0.000	0.491
Authentic Scientific Lab Practices	9.54	12.93	+3.39***	0.011	1.009	0.000	0.582

2.7 Discussion

Recent studies of course-based laboratory research aims to improve students' critical thinking and their preparation to become future scientists (Bruehl et al., 2015; Carmel & Yezierski, 2013). Course-based research studies have shown that students in such courses report improved critical thinking, including greater data collection and analysis skills, and enhanced scientific reasoning (Linn et al., 2015). Using pre- and post-tests and surveys, this study implemented a CURE via CASPiE and showed that afterwards, students perceived greater authenticity of scientific laboratory practices, more learning through the laboratory, and higher interest in chemistry/science, than before. After CASPiE, students showed higher critical thinking test scores than before, and this gain was higher for students who viewed the CURE activities as more authentic than the laboratory activities in the previous course. These three findings indicate positive educational outcomes associated with participating in the CASPiE research experience for this sample of military academy cadets. These findings are further discussed below.

The self-report results displayed significant increases after CURE participation. These results suggest that students felt that they learned more, gained more of an interest in chemistry/science, and did more authentic scientific work in the CASPiE experience than in a traditional laboratory class. They are also factors that are related to critical thinking increases in previous CURE implementations (Wink & Weaver, 2008).

Critical thinking gains across the semester were consistent with previous CASPiE research (Gasper & Gardner, 2013). Significant gains in total CAT score occurred for participants during the treatment semester. CURE participation was also related to a significant increase in students' perceived authenticity of the laboratory experience. Students who viewed the CURE activities as more authentic had higher increases in critical thinking (on the post-test compared to the pre-test). This suggests that the more authentic that students viewed the experience, the more impact that it had on their critical thinking. This relationship is fundamental to the CURE experience as the primary focus of any CURE is to give students an authentic perception of research. The results suggest a relationship between CURE participation, its authentic research activities and critical thinking gains for these military academy cadets. The CASPiE implementation at USMA was successful in terms of both students' perceptions and their critical thinking. Given the value of critical thinking, perceptions of greater authenticity, greater learning and greater interest in chemistry for future endeavors both scientific and otherwise, these results extend the CURE literature in important ways.

A link between authentic practice and critical thinking is an important finding that can inform and improve student learning during chemistry courses. Engaging with the course content in an authentic way can help students think critically about possible outcomes or extensions of the research. Hence, instructors who develop authentic curricular materials might help students improve their critical thinking. Educators and curriculum designers can also use CUREs as a vehicle to deliver a real research experience to students and to systematize undergraduate research experiences. CUREs offer research experience to many undergraduate students at one time (Auchincloss et al., 2014). Incorporating such experiences into the curricula can streamline this process, making it easier and less expensive.

While CURE research has shown connections between authentic science practice and critical thinking (Gasper & Gardner, 2013), this relationship requires further investigation. This study adds to the body of CURE literature by showing that students who perceive laboratory activities as more authentic show greater critical thinking gains. The next step for this implementation of CASPiE is to address issues reported by faculty instructors. They noted that this CURE course was very time-consuming and labor-intensive. The instructors spent a lot of time trying to set up laboratory times, experiments, and curricular material. They were not able to collaborate efforts much as the course incorporated three projects running concurrently. One possible way to reduce their time and effort is to change the curriculum from three projects to one project.

Table 2.3 Regression Models Predicting Critical Thinking Score

	Model 1 May	Model 2 + Authenticity	Model 3 + Authenticity *May	Model 4 + Gender	Model 5 + Ethnicity
May	2.59*** (0.73)	1.93* (0.97)	-6.36 (4.02)	-5.90 (4.02)	-5.08 (4.04)
Authenticity		0.11 (0.16)	-0.13 (-0.66)	-0.12 (0.20)	-0.11 (0.20)
Authenticity*May			0.70* (0.33)	0.67* (0.33)	0.66* (0.33)
Gender				-0.24 (1.01)	-0.27 (1.01)
Ethnicity					0.30 (0.57)
Intercept	24.35*** (0.51)	23.36*** (1.58)	25.60*** (1.89)	25.59*** (1.88)	25.17*** (2.05)
Explained Variance	0.08	0.07	0.10	0.10	0.11

2.8 Limitations and Future Work

Some limitations of this research study include both design and implementation aspects. Cadets at military academies are engaged in an academic environment that is far different than most undergraduates in traditional universities. The results of this study are only generalizable to an extent. One cannot simply assume that increases in CAT scores for these students are indicative of increases that would occur in many other academic settings. This point is further illustrated by the lack of a true control/treatment experimental design. Though interactions in regression analyses are robust in telling of relationships between variables, a classical control-treatment experiment would demonstrate all outcomes of CUREs when compared to traditional settings.

The CURE program at USMA has continued to be implemented in second semester chemistry courses and is now the main method of educating all cadets in this level of general chemistry. This study further extends the sparse research literature on the effects of CUREs on military academy cadets. CASPiE studies have examined the effects of the program on several student outcomes, such as student views of the nature of science and affective gains (Weaver et al., 2008). This study in conjunction with Gasper and Gardner (2013) adds critical thinking to a target outcome of CURE. Some next steps in the evaluation of this type of instruction include considering other educational outcomes, such as creative thinking or a standardized content exam. Future studies can also measure longer-term critical thinking effects with a delayed post-test. Future research can also examine the applicability of content learned. The course-based research model of instruction gives students a deep understanding of research techniques and content that is specific to this project. This raises the question of what happens to that knowledge and whether students can apply it to other situations outside of the traditional curriculum.

2.9 Acknowledgements

The authors would like to acknowledge the Center for Environmental Science and Technology at the State University of New York – Cobleskill for the allowing cadets to participate in the waste-to-energy gasification research project.

2.10 Appendix

The largest number of cadets (42) selected the Chemical Engineering Group. This team worked to determine which scrubbing method (e.g. solid phase material or liquid solvent) was most effective at removing unwanted tars from the gas. Removal of tars is essential if the gasifier is to feed fuel to an Army power generation unit without causing undue wear-and-tear on the system. In order to accomplish this goal, cadets were first taught how to use ChemCAD modeling software and asked to read a number of papers related to gas scrubbing systems and tar removal. After using ChemCAD to reproduce the results of a related paper, the cadets were allowed to either continue with modeling or conduct hands-on experiments. The majority of cadets continued with hands-on work with a liquid solvent or solid-phase scrubbing material of their own selection and design (rice husks, propylene glycol, motor fuel, aerogel, etc.). Cadet groups developed a wide variety of different hypotheses. First, they tested the scrubbing material in ChemCAD and then compared their predictions to the actual results obtained through hands-on experimentation. The hands-on testing of scrubber solvents occurred using a gasifier the students designed and built as a team.

Cadets with a strong interest in the Life Sciences (31 cadets) selected the Toxicology Group. There is a valid concern that the syngas and waste tar created by the gasification process could be hazardous to humans and the environment. There is potential for exposure to the fumes of the solvent or the solvent itself during maintenance, storage, or disposal. As one step towards identifying any potentially negative health effects, cadets tested the solvent using the Ames assay (Ames, 1979). This simple assay identifies chemical substances that are mutagenic to a modified strain of Salmonella bacteria; the assay is relatively inexpensive and requires extensive use of both positive and negative controls as well as replicates, so the assay itself serves as an excellent teaching tool for experimental design. Cadets started with a harmless strain of E. coli to learn basic aseptic techniques. Next, cadets performed the Ames assay by exposing Salmonella typhimurium to a control substance or the polishing fluid (propylene glycol) that had been used to clean the gas generated by the trash. After performing two iterations of the Ames assay, cadets had enough preliminary data and experience to design their own experiment using appropriate positive and negative controls. The cadets' hypotheses varied substantially from group to group. Some cadets tested various concentrations of solvent, others tested multiple strains of the bacteria, and others exposed bacteria to either the solvent fumes or the actual gas produced by the system before and after scrubbing. Several cadets (14 cadets) were interested in the Analytical Chemistry Group. These cadets worked in small groups of 2-4 cadets to analyze scrubbing oil for the presence of poly-aromatic hydrocarbons (PAHs) using a GC/MS. GC analysis is generally not one that supports the processing of oil samples. However, the developed method separated the non-polar fraction of the oils and saponified them so that they became aqueous (Mathison & Holstege, 2013). The goal of this project was to compare the GC results with a known standard to identify the different polycyclic aromatic hydrocarbons (PAHs) in the resultant oil. PAHs are known to be dangerous when inhaled, therefore it is important to identify if the gasification process is producing a dangerous environment for soldiers. The module began with an introduction to the GC instrument as well as some examples of what chromatographs look like and how to properly interpret them. After the initial instruction, the skill-building modules included the development of standard curves with known solutions. This allowed cadets to familiarize themselves with the process of identifying specific peaks on a graphical output from these types of experiments. The process of prepping the samples and placing them into the instrument queue also proved to be a vital learning experience for the ensuing project. Cadets were evaluated in a formative manner by their laboratory notebooks as well as their ability to interpret results alongside the instructor.

The skill-building laboratory sessions varied in content and depth across the modules, but all generally contained hands-on laboratory activities that mirrored the results of a research publication with the end goal of developing a standard method for proceeding. The toxicology group began by learning how to safely and aseptically handle bacterial cultures before learning to conduct the Ames assay using Salmonella typhimurium. The chemical engineering group began to create a ChemCAD model of an actual experimental publication to use as a baseline to compare results. The analytical Chemistry group created a standard reagent curve for a mix of Poly-aromatic hydrocarbons. Following the skill-building modules, cadets engaged in a research collaboration meeting with other groups from different areas. They then began to develop their hypotheses for their own research project. These hypotheses were submitted and reviewed in an iterative process with the corresponding instructor. Students executed their planned experiments and adjusted as necessary based on their results. After completing their experimental work, a short poster training session provided each group of two to four cadets with sufficient guidance to create their own research poster. Cadets also visited poster sessions of upper class research cadets shortly before their own poster was due. CASPiE instructors reviewed each draft poster at least once and provided feedback on both design and content. Cadets concluded their CASPiE experience at a poster session attended by a wide audience of their peers, upper class cadets, instructors and senior leadership at West Point as well as outside guests, including the lead researchers of the project.

Table 2.4 Correlation Matrix of Key Variables

	May	Authentic	AuthMay	Learning	LearnMay	Motivation	MotivMay	Gender	Ethnicity
May	1.00								
Authentic	0.6165	1.00							
AuthMay	0.9775	0.6998	1.00						
Learning	0.2794	0.3672	0.3251	1.00					
LearnMay	0.9897	0.6396	0.9809	0.3555	1.00				
Motivation	0.2199	0.5476	0.2988	0.4107	0.2585	1.00			
MotivMay	0.9480	0.6701	0.9659	0.3387	0.9574	0.4249	1.00		
Gender	0.0034	0.1048	0.0105	-0.1741	-0.0117	0.1090	0.0061	1.00	
Ethnicity	0.0017	-0.0374	0.0045	0.0160	-0.0022	0.0096	0.0091	0.610	1.00

CHAPTER 3. THE EFFECT OF EXPANSIVE FRAMING ON TRANSFER ABILITY: A STUDY OF COURSE-BASED RESEARCH AT THE UNITED STATES MILITARY ACADEMY

3.1 Abstract

Course-based Undergraduate Research Experiences (CUREs) provide opportunities for undergraduates at relatively low education levels to engage in authentic research experiences early in their careers. This not only gives them an experience that aids them in deciding the direction of their future career, but gives them a unique opportunity to apply the material that they learned in the course. To investigate this application, this study uses transfer assessments to examine what factors influence transfer ability among CURE participants. Transfer is the mapping of a concept into a novel situation where it is appropriate, thus demonstrating deeply structured content understanding (Chi & Vanlehn, 2012). If the critical thinking associated with CUREs that was found in study 1 is sufficient for high levels of subsequent transfer, then the addition of other transfer-promoting instructional practices should have little effect. On the other hand, if large benefits to transfer are consistently found with the transfer-promoting instruction, then this may be a complementary strategy worth including with other CURE experiences beyond CASPiE. The transfer-supporting instructional practices were expansive framing and inventing with contrasting cases (ICC). Expansive framing is a mode of instruction that directly informs students of future instances in which the material can be applied

other than simply course assessments. The control group received instruction that was bounded in its framing. To avoid instances of negative or overzealous transfer, Inventing with Contrasting Cases was implemented as a method of instruction. This is a method of presenting two cases with noted difference to instruct the material and mitigate instances of overzealous transfer (or transferring material where it is not appropriate) (Schwartz et al., 2012). Qualitatively, differences in student answers between these conditions were examined. Top-performing students appeared to have a deeper understanding in the treatment condition on a Gas Chromatography transfer assessment than those in the control condition. Instances of negative transfer appeared to be reduced. However, no differences between conditions were found on a subsequent topic, kinetics, due to a ceiling effect.

3.2 Expansive Framing and Transfer

It is important for students at all levels to leave a course with an understanding of the applicability of the content of the course. Likewise, our assessments and interventions must line up with these course goals and constructive alignment must be achieved by course interventions (Biggs, 2003). Therefore, expansive framing can be an effective way to achieve the goal of showing students the importance of the material taught in the course. Expansive framing can be best defined in the statement by Engle *et* al. (p. 217):

> *Our contention is that the first kind of framing, which we refer to as bounded, will tend to discourage students from later using what they learn, while the second, which we refer to as expansive, will tend to encourage it* (Engle, *et* al., 2012).

Framing instructional materials in this way gives students the understanding of why they should invest their time and efforts into learning material. Expansive framing includes instruction that pushes students to think with a broader perspective about how the material is necessary to conceptualize outside of an exam or a final course grade that they receive. This is shown by Engle *et* al. (2006) in the instruction of pressure differentials by using anatomical systems like blood flow or the respiratory system. The bounded condition in this case was the instruction of material to memorize about pressure differentials accompanied with practice problems. This instructional framework has been previously shown to impact various learning objectives. Recently, an expansively framed computer science course was developed and successfully improved learning of algorithmic concepts of computational thinking (Grover & Pea, 2016). In 2011, Engle *et* al. showed how expansively framed tutoring in biology courses can significantly improve transfer (Engle *et* al., 2011). Given this previous work, Engle *et* al. (2012) suggested that expansive framing should be linked to transfer in future studies with a control-treatment experimental design:

> *Another way to learn whether and how framing affects transfer is to make systematic comparisons between and within classroom-based case studies. To compare the effects between bounded and expansive framing, teachers teaching multiple sections of the same course can be encouraged to implement more bounded or more expansive framing in order to see what benefit, if any, the expansive*

implementation has on students' propensity to demonstrate different kinds of transfer.

This previous work provides rationale for studies such as this one in which a control-treatment design is used to examine differences between students' ability to transfer material instructed in an expansive manner. For the purposes of this study, transfer is defined as demonstrating student understanding of a concept on a deep level. This is achieved by looking to see if students can map concepts from a course onto novel situations where they are appropriate (Chi & VanLehn, 2012).

One of the most difficult components of transfer research and subsequent transfer promoting instructional methods is avoiding promoting overzealous transfer. Overzealous transfer is defined as a situation in which students transfer solutions. These solutions seem to to work well for students and therefore appear to be positive. However, they do not show novel learning and are therefore negative (Schwartz *et* al., 2012). Overzealous transfer includes an overgeneralization of skills or techniques associated with a content area and display a failure of students to demonstrate deeply structured knowledge. It is important that transfer researchers and curriculum developers find ways to evaluate and mitigate instances of overzealous transfer. In the 2012 article, Schwartz *et* al. defined Inventing with Contrasting Cases (ICC) as a method of avoiding overzealous transfer. ICC is a method in which students are presented with contrasting cases that show subtle differences around a concept and instruct students in a way that encourages them to understand these differences. Students can then map this knowledge onto a new situation in a correct way as they understand these subtleties and apply them.

Inventing with Contrasting Cases was used by Schwartz and Bransford (1998) and later incorporated into the Preparing for Future Learning framework developed by Bransford and Schwartz (1999) and Schwartz, Bransford and Sears (2005). In the 1998 study, contrasting cases encouraged deeper understanding as opposed to surface level understanding. This intervention prepared students to learn more from a lecture than those who engaged in other more traditional learning activities such as reading or note-taking. Exposing them to contrasting cases proved to be beneficial for student understanding by helping them discern key features of an idea that the subsequent lecture further explained. ICC has been shown in previous studies to have many beneficial effects in preparing students to learn. The students in the ICC case were better able to reproduce the ratio structure of density and other physical concepts (Schwartz *et* al., 2011). This study further showed that high and low achieving students were benefitted by ICC. ICC has been shown to be an effective way to teach material within a lecture-based course, however there is a need for studies that demonstrate expansive framing and ICC within a predominantly laboratory-driven course. Another example occurs in a Physics course in which Faraday's Law was instructed using contrasting cases. In this course, students were shown to be better prepared to learn subsequent physical laws such as Lenz's Law as opposed to students who were simply told the materials (Kuo & Wieman, 2016).

3.3 Course-Based Undergraduate Research Experiences

Undergraduate research is a common program that is available to students at most universities. These research experiences tend to include work outside of the classroom for select students that seek it out. They are known to prepare students for graduate level or industrial work in STEM. However, Bangera and Brownell (2014) point out that many students do not have access to such experiences. Minority students from diverse backgrounds generally do not represent most of the students enrolled in these programs. To address this issue, Bangera and Brownell call for Course-based Undergraduate Research Experiences (CUREs) to be a required component of introductory STEM courses. These types of curricular experiences give many students the opportunity to participate in research projects while taking introductory level courses in STEM (Auchincloss, *et* al., 2014). CUREs represent a broad range of educational interventions that proceed in various forms but all give students access to authentic STEM practices within their coursework.

One model that has been developed to implement CUREs is from the Center for Authentic Science Practice in Education (CASPiE). The CASPiE model of instruction is defined by Szteinberg and Weaver (2013, p.24) as "a multi-institutional collaborative project that aims at providing course-embedded authentic research experiences for undergraduate students during their early years in college, specifically during their general and organic chemistry courses)." The CASPiE model of instruction is one that gives students a research project to work on throughout the semester. The students work on skill-building modules to learn basic concepts related to the research project, they then come together as a team to create hypotheses for their specific project to advance the research. Students then collect data and carry out their own designed experiments, summarize results, and report conclusions in a culminating research presentation (Weaver *et* al., 2008). The present study was performed with military academy cadets. This has proven to be an effective population for CASPiE research as previous studies have linked critical thinking gains to authenticity (Chase *et* al., 2016). This instructional method served as the backdrop for the current study.

3.4 Study Overview

This study examines the relationship between expansive framing and ICC and transfer within a CURE context. Specifically, students' ability to transfer course materials are compared between conditions of expansively versus the traditionally instructed material. Also, students that were in the treatment group are compared with later in the course when they are instructed in the traditional manner. This shows how teaching material in an expansive way can possibly impact other course content later in the semester. The study uses quantitative methods and qualitative comparisons to address the following research questions:

- What is the impact of the expansive framing on transfer performance in military academy cadets enrolled in a course-based undergraduate research experience?
- What is the impact of expansive framing on instances of negative transfer?

Hypothesis 1: *Expansively framed instruction increases deeper understanding in cadets which fosters transfer.*

Hypothesis 2: *Using Inventing with Contrasting Cases, expansively framing instruction decreases instances of negative or overzealous transfer.*

This research was done at the United States Military Academy (USMA) at West Point, NY. The academy is known around the world for producing military officers as well as providing an undergraduate education. Those enrolled at this institution (known as "cadets") exchange their education and tuition costs for active duty military service after graduation. This not only provides them with an education, but effectively guarantees employment upon completion of their degree. Two sections of General Chemistry 102 (the second semester course) were studied for the purposes of this paper. Class sections are approximately 20 cadets in size and instructed by either a civilian professor or active duty military officer. Military officers that serve as teaching faculty at USMA are trained in instruction pedagogy upon entering the position and all have attained a minimum Masters level education in the content area (chemistry). The teaching format of courses is known as the “Thayer Method” and incorporates a problem-based approach to instruction at all levels (Shell, 2002). The project objectives of the cadets enrolled in the course was to assess the nutrition of primates by measuring the amounts of sugars in the leaf extracts eaten by those primates. Specifically, students extracted sugars from the leaves and used a Gas Chromatograph/Mass Spectrometer (GCMS) to analyze the amounts and types of sugars that were present in the samples. The chemical principles included in this project involved solubility of sugars, instrumentation, extraction, chemical work-up, and data analyses procedures commonly used in chemistry research. The course schedule is presented below in the figure.

Lsn	Title
7	CASPiE Introduction Skill Building Lesson—2h
12	CASPiE - Experiment I - Skill Building Lesson—2h
19	CASPiE - Experiment 2 - Skill Building Lesson—2h
23	CASPiE - Experiment 3 - Skill Building Lesson—2h
29	CASPiE - Research Collaboration/Hypothesis Development
30	CASPiE - Cadet Experiment 1—2h
31	CASPiE - Cadet Experiment 2—2h
32	CASPiE - Cadet Experiment 3—2h
34	CASPiE - Cadet Data Analysis & Poster Prep—2h
35	CASPiE - Cadet Poster Revision
39	CASPiE - Presentation practice—3 & 4 May
40	CASPiE - Capstone Event

Figure 3.1 CASPiE Course Schedule

3.5 Method

This experiment was a 2 X 2 crossover quasi-experimental design with control and treatment conditions that were eventually reversed by topic (See Figure 3.2). The design implemented here is appropriate because it allows for selection of students that are taking a specific course and allows for selection of different treatments by group. Students in treatment groups received a single topic taught in an expansive manner with ICC, in which they were deliberately instructed about the situations in which the current instruction will be useful in the future. This group received the treatment whereas control group students did not. The groups were then flipped and the previous control group became the treatment group. The experimental design allowed for two simultaneous quasi-experiments to examine differences. This design further gave a control/treatment scenario that validated comparisons across groups. It was impractical in this case to separate out the entire course by instruction as it was very important to department officials that students were not disadvantaged by a research study based upon which section of the class that they were in. The design gave the ability to give each group of students a similar experience while allowing for control/treatment group comparisons.

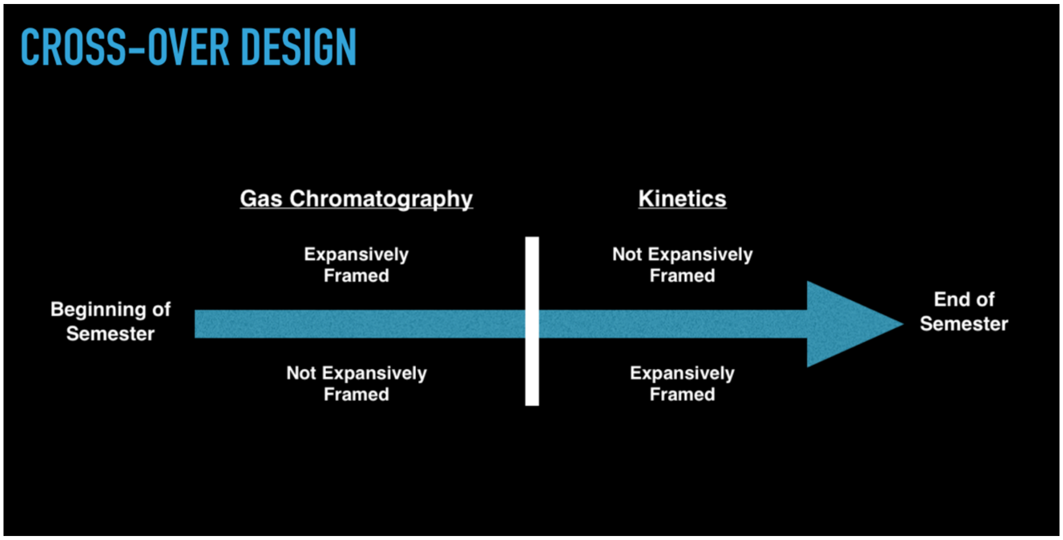

Figure 3.2 Crossover Experimental Design

This study took place at the United States Military Academy at West Point, NY. The participants (38 cadets) were all enrolled at this army undergraduate institution. They attended classes towards an accredited degree program and received military training eventually leading to a position of a second lieutenant in the United States Army. Data were collected to compare the control and treatment groups as a between groups study. One group received transfer-supporting material through the semester on one of two topics. The other group received transfer-supporting materials on the second topic. That way each group received one topic that was taught in the manner that demonstrated its necessity for some future learning activity. They were both analyzed in a similar fashion yielding an overall score on each topic's transfer activity. Then the resultant scores were compared with each control variable. Results were reported by topic. The transfer assessments show how the gas chromatograph instrument operates and the importance of various components of it. Further, for the kinetics assessments, students are mapping the importance of activation energy and catalysis into a new situation.

Transfer activities were scored by a rubric developed by expert analysis of questions. The scores that students received on these activities were then added to a linear regression analysis to determine significant impact of the binary variable of control/treatment (expansive framing/non-expansively framed instruction). To validate the content used for the transfer assessments, multiple content experts were used. Chemistry instructors as well as researchers examined the assessments and verified their content validity. To validate the rubrics for scoring these activities, multiple scorers were used to verify the score of the transfer assessments. After the assessments were scored by multiple reviewers, if they did not reach the agreement, a discussion took place between the reviewers, and adjustments were made to the rubric and the process restarted until agreement was reached on the correct method of scoring. These rubrics are displayed in the appendix Table 3.4. Scores of negative transfer instances were coded any time that the students stated that the only difference between the two instruments was that one method was “destructive” or “produced waste” in the output thereby revealing an understanding that was true for the first case but not for the novel situation (i.e., the very definition of overzealous transfer?).

3.6 Results

After scoring, the results were entered into a linear regression to examine significant effects. The distributions of scores are reported below. The distributions show differences between the control and treatment groups as the number of zero scores is much lower as well as the 2 and 3 scores being higher. When examining the results of the kinetics transfer assessment, the distribution was similar for both control and treatment because both conditions scored near ceiling on the transfer measure. Below are also the results of the regression for kinetics. Despite the lack of significance in results, the mean differences are in the direction favoring the treatment.

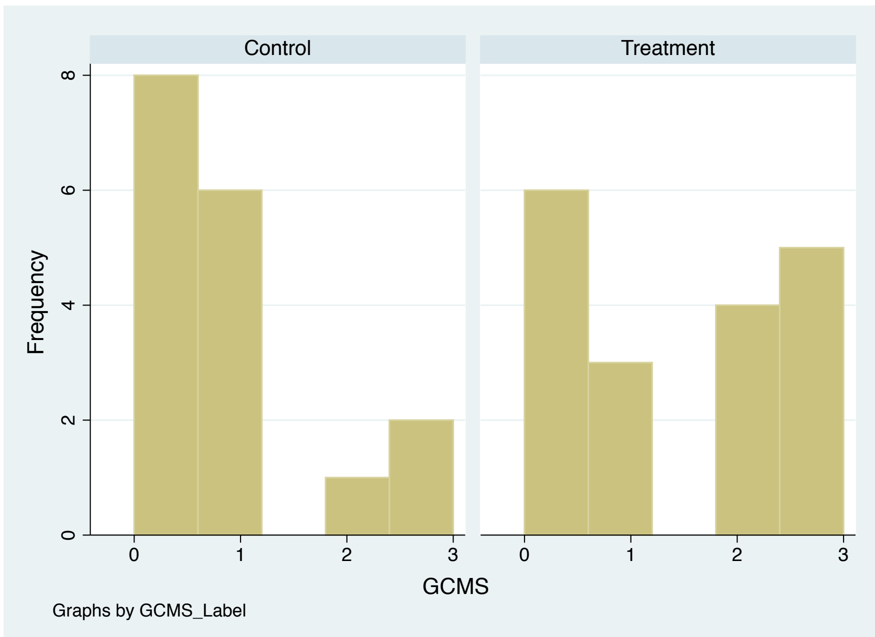

Figure 3.3 GCMS Transfer Assessment Distribution

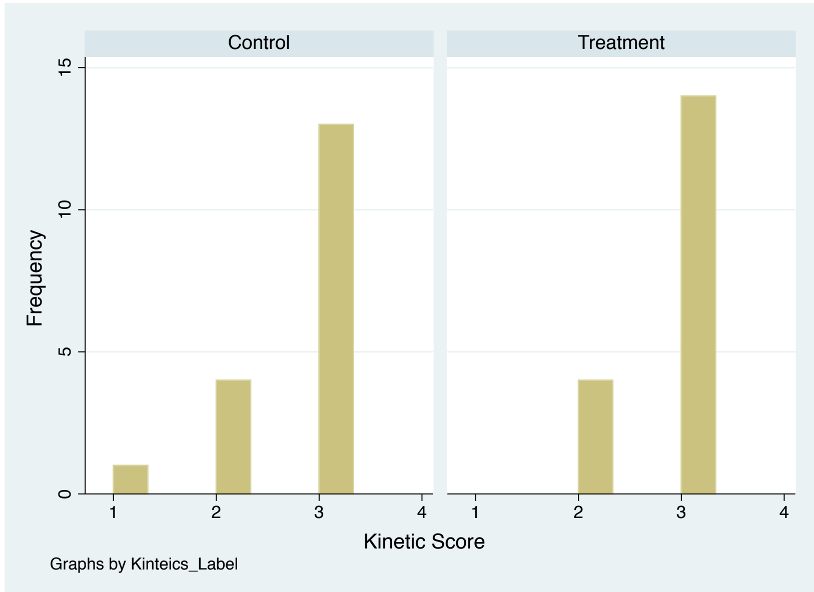

Figure 3.4 Kinetics Transfer Assessment Distribution

Table 3.1 Treatment Differences – Regression Results

Outcome	Treatment Coefficient	Standard Error	P-Value
GCMS	0.621	0.386	0.117
Kinetics	0.111	0.173	0.524

In the following examples, top performing students in each condition appeared to show some differences in overall depth of understanding, favoring the ICC + Expansive Framing Treatment condition. Top performing students are those that received a perfect score of three points on the transfer assessments. Low performing students are those that received a score of zero on the transfer assessments.

Table 3.2 Top Performing Students – GCMS Answers

Control		Treatment	
Student Identifier	Response	Student Identifier	Response
176	*The difference in the output will be the different retention times of the different types of sugar. In the GC/MS it takes much longer but in the GC/FID you will lose the precision of detecting the different types of sugars.*	87	*The GC/MS organizes ions based on their mass, the flame ionization detector helps identify retention times. With the GC-FID you lose the isolated identification of each compound in the sample. The GC-FID provides you with retention times where you can compare known retention times and then identify compounds.*
136	*The GC with FID will lose more detailed information about the structure of the molecules. The FID shows us everything that burns in a hydrogen flame whereas the MS may not show as many different molecules but will suggest more information on those molecules such as boiling point and structure.*	71	*When we switch from MS to FID, we will be going from learning the mass, time the substance took to get through the instrument, and quantity to just the time and quantity of the substance. Also with the FID, we will lose the sample do to the flame.*

Student 176 correctly identifies the importance of retention times in the flame ionization detector (FID). Further, the identification component of mass spectrometry is mentioned. This is important as it shows that the student understands the output differences between the instruments. The other control student here (136) correctly identifies the detail lost with the FID. The student incorrectly states that information is gained by the FID but then correctly states that the mass spectrometer will show structure of the molecule. Treatment student 87 shows a deeper understanding of the material as they speak about specific components and processes of the instruments. The student then focuses their answer on the retention times (the primary output of a gas chromatograph). Student 71 points out the types of information that each instrument provides and correctly identifies what is lost when moving from one to the other. Not only do they provide retention time as an output value, but describe what retention time means and how it is provided. This suggests a deeper understanding of the working of the instrument.

Table 3.3 Low Performing Students – GCMS Answers

Control		Treatment	
Student Identifier	Response	Student Identifier	Response
106	*Heat will be able to be read. Lose the amount of sugar in the solution*	152	*GC-FID also produces waste. You lose detection of non-ions.*
199	*Slight difference, the FID lets some material go to waste while the GC/MS does not. The GC-FID would have a lower output.*	73	*The output would be based strictly on boiling point now.*

Student 106 incorrectly associates a flame detector with a flame as a heat source. This resulted in their description of a heat-based output from the instrument. Further the student states that relative amounts will be lost when moving to an FID. This is the opposite as an FID uses retention times and current to report relative amounts. It appears as if the student is using context clues of the problem to guess at the solution. Student 199 incorrectly uses the diagram to make the claim that the mass spectrometer does not waste the sample. The notion that the FID has waste is simply referring to the further analyses that could happen after separation by chromatography. The treatment student 152 wrote about waste production. This may be a result of looking at the diagrams and noticing the production of waste. The second statement by the student is about detection of non-ions. This shows some understanding of the process of chromatography as polarity is commonly used to separate compounds (though not exclusively the only way). Finally, student 73 appears to be associating the "flame" in flame ionization detector with a boiling point of molecules.

Table 3.4 Instances of Negative Transfer – GCMS Answers

Control		Treatment	
Student Identifier	Response	Student Identifier	Response
18	*It will completely destroy the sample but it will yield the same results.*	91	*With the flame ionization detector, the sample is destroyed and thus can only be studied once through the GC. If both machines are running properly, the results should be the same.*
105	*The flame ionization energy destroys some of the sample.* Description: This student inappropriately transfers the destructive method of gas chromatography as destroying the sample.	57	*The units will not be the same and therefore the chromatogram for GC with FID will be different. You lose your sample when you use FID because it is consumed during the process.*

Both methods are known as destructive methods of analysis. This is a fundamental misconception of the differences between "waste" and "destroy" in terms of analyzing a sample. Student 18 not only suggests that these instruments will yield the same results, but further inappropriately transfers the destructive method of gas chromatography as destroying the sample. Likewise, student 105 inappropriately transfers the destructive method of gas chromatography as destroying the sample. This comes from the idea that a flame burns the sample at the end of the column. However, in both cases, the material is not returned and the method therefore is destructive. Treatment student 91 presumes that both instruments provide the same information and further incorrectly transfers the idea of the sample being destroyed. Student 57 also incorrectly transfers the idea of the sample being destroyed or "consumed" in this case. They also suggest that the units will not be the same but doesn't specify what that means. Overall, there were 3 instances of negative transfer coded in the treatment group and 7 instances of negative transfer coded in the control group. This difference, though not statistically significant, supports the mitigation of negative transfer by Inventing with Contrasting Cases.

3.7 Discussion

This is a study comparing methods of supporting transfer with a control of the CASPiE condition. Though results were in the expected direction, there were no significant benefits observed by the treatment condition. It's possible that CASPiE is already inducing transfer-supportive thinking. An alternative possibly is that there are benefits, but not enough statistical power to detect changes. So, we can look more closely at different levels of student understanding by the examination of different levels of transfer performance.

When examining the differences of top performing students (Table 3.1), it appears as if students who scored well and transferred material had a grasp of material in a deeper way. The answers provided not only spoke of the output received from the instrumentation, but detailed the specific parts of the instrument and their functionality.

This supports the relationship between deeper understanding (evidenced by effective transfer) and expansively framed instruction with ICC. This could be for a variety of reasons as highlighted by Engle *et* al. (2012). When instruction is framed in an expansive manner, students see a broader context for its use and therefore can better structure the knowledge for transfer. Mapping deeply structured knowledge in a transfer assessment is contingent on this type of encoding upon learning (Chi & VanLehn, 2012).

One low-performing student within the treatment condition displayed some understanding of the process of chromatography. Other than this possible structuring of content knowledge, it appears as if the low-performing students followed the same process regardless of instructional method. This process involved reading the question and examining the diagram for context clues, then providing an explanation to support their preconceived conclusions. This suggests that the expansive instruction used in this study does not affect low-performing students in the same manner that it does top-performing students.

Based upon previous work by Schwartz et al. (2012), the Inventing with Contrasting Cases component of the study should have mitigated instances of negative or "overzealous" transfer. Table 3.3 shows instances where students misappropriate the term "destructive method of analysis" with a sample being physically destroyed. In analytical chemistry, destructive methods of analysis include both the flame ionization detector (GC-FID) and the mass spectrometer (GC/MS). The term "destructive" in this case refers to the fact that when running the sample within the instrument, the sample does not come back out at the end. Therefore, you must "sacrifice" a portion of your sample to run these types of analyses. The negative transfer involves the misconception that a sample is obliterated in the process, violating the most fundamental law of conservation of mass that students are taught at the outset of their chemistry course. The surface level understanding of the instrumentation causes students to examine the diagram alone and see the flame and assume that the flame in the GC-FID is what is causing this sample destruction. However, that is not what is meant by the term destructive method of analysis and therein lies the misconception. Though students displayed (Table 3.3) instances of negative transfer regardless of treatment, the experimental condition showed less than half of the instances of negative transfer as the control (3 in the treatment versus 7 in the control). This reduction in amount of negative transfer can be theoretically attributed to the ICC condition in the treatment. The contrasting cases used in instruction gave students the opportunity to see the functionality of the different pieces of the instrument. Students understand the purpose of the flame and other pieces of the Gas Chromatograph that analyze a sample. The negative transfer occurs from students hearing the words "destructive method" to classify certain methods of chromatography and then answer the transfer assessment based upon a surface examination of the diagrams provided.

This manuscript adds to a body of literature that supports a relationship between expansive framing and transfer ability among students. One of the interesting findings with this study is the gains made by top-performing students as opposed to low-performing students who did not show similar effects in the transfer assessment. Further, this study supports the mitigating of negative or overzealous transfer instances by the incorporation of Inventing with Contrasting Cases to prepare for future learning (Schwartz & Bransford, 2005). This notion is displayed by the qualitative comparisons of this study (showing half the instances of negative transfer when compared to the control group).

This study further contributes to the Course-based Undergraduate Research Experiences literature by displaying an instance of course-based research and showing how this environment can facilitate instruction in an expansive way as well as support transfer. The CASPiE model has been incorporated into military academy instruction prior to this study (Chase *et* al., 2016) and has shown links between critical thinking and perceived authenticity. The CASPiE model of instruction has not only displayed gains in critical thinking, perceived learning, and authenticity at the United States Military Academy, but now in this manuscript has shown effects in what cadets do with the knowledge after instruction. Not only can the instruction method of this study foster transfer, but inherent in instruction that is expansive is an authenticity piece. This has been recently shown by Kapon *et* al. (2016) as the two are linked within scientific classrooms. Authenticity, which as indicated by previous work is related to gains in critical thinking (study 1), is therefore something that educators should strive to increase within scientific classrooms.

3.8 Limitations and Future Work

Within this study are some limitations apparent in the design and outcome. Statistical results of transfer assessment scores show that the study does not have enough power to differentiate statistical differences of means. This would indicate that there weren't enough students involved to see significant differences though mean differences trended in the expected direction. Further, in the kinetics transfer assessment, there was a ceiling effect displayed as students scored high regardless of treatment group. It appears as if the difficulty of the items in the GC/MS assessment were more difficult than the kinetics transfer assessment. This did not allow for accurate comparisons in performance on transfer assessments. Future work should include more students on a larger scale with assessments that are of similar difficulty.

3.9 Appendix

Below are the activities that the students used in the course for instruction as well as transfer assessments.

1. You are working in an industrial facility that makes prescription drugs. Due to previous mishaps in which companies have filled drugs with filler or impurities, the FDA enforces standards about how pure these drugs have to be. As a chemist in quality control, one of the head linesman from the manufacturing line comes into your lab and tells you that one of the dispensers looks like it could have some impurities in it and that may have ruined a sample but he isn't sure. Pharmaceuticals are expensive to make so the last thing you want to do is throw out a good sample on a hunch. What do you do to test this?

2. Many laboratory activities in general chemistry include the use of a spectrophotometer to test for wavelength using the equation:

$$\lambda = elc$$

where e = the molar absorptivity constant, l = the path length of the instrument, and c = concentration.

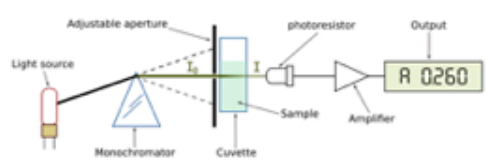

Figure 1. https://commons.wikimedia.org/wiki/File:Spetrophotometer-en.svgSpectrophotometry

When might you use a spectrophotometer versus using a gas chromatograph? What is the difference between the two?

Figure A.1 GCMS Transfer Instructional Activities

3. In identifying your sugar solution, the GC/MS says that there is a "fatal error" and then shuts down. The only other option is to use a different GC. This one, however is an FID (flame ionization detector). What difference will that make in the output? What information do you gain from this? What information do you lose?

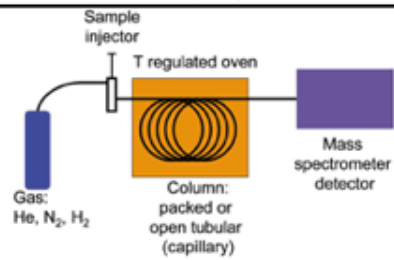

Figure 2. https://en.wikipedia.org/wiki/Gas_chromatography–mass_spectrometry

GC/MS Diagram

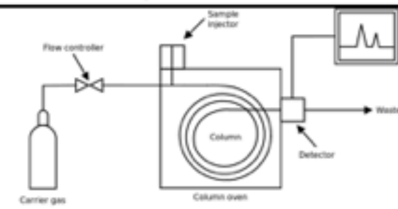

Figure 3. https://commons.wikimedia.org/wiki/File:Gas_chromatograph-vector.svg

GC-FID Diagram

Figure A.2 GCMS Transfer Assessment

The following is the reaction that displays the degradation of o-zone in the o-zone layer. On the left is the process that occurs naturally and on the right is in the presence of chlorine (from chlorofluorocarbons) in the atmosphere.

$O_3(g) + O(g) \rightarrow 2\ O_2(g)$

$Cl + O_3 \rightarrow A + O_2$ E_A = _LOW (low or high)

$+\ A + O \rightarrow ClO + O_2$ E_A = _LOW (low or high)

$O_3(g) + O(g) \rightarrow 2\ O_2(g)$

Below is an energy diagram of these reactions. Using this information, what is the identity of **A** in the reaction. Fill in the blanks with the missing information about products and activation energy. Which line on the energy diagram represents each process of o-zone degradation and how do you know?

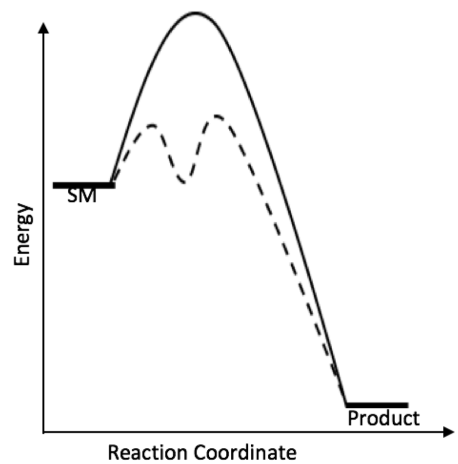

Figure A.3 Kinetics Transfer Instructional Activity

When planning a reaction for their company, a manager consults your advice on how to proceed. The reaction in question has a known catalyst that speeds things up, but is somewhat expensive. They turn to you because they aren't exactly sure what this whole "catalyst" thing is for anyway. In terms of energy differences, describe how a catalyst effects a reaction. Draw a diagram showing the difference of a reaction with and without a catalyst. Propose two situations: one in which a catalyst would be helpful for a company and one in which there would be a better alternative.

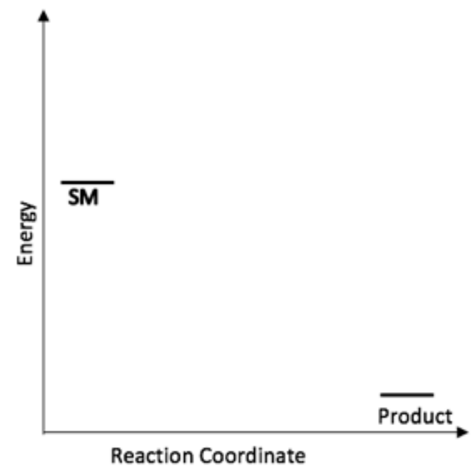

Figure A.4 Kinetics Transfer Assessment

Below are the rubrics used to grade the different components of the transfer assessments. Each assessment has three individual components and therefore is scored based upon the appearance of the desired features. They were not scored based upon the quality or depth of the specific features, but simply their identification of the correct ones.

Table 3.5 Rubric for Scoring Transfer Assessments

Question	+1	+1	+1
Gas Chromatography	Structure/Mass information	Flame shows retention times and amounts only	GC/MS gives more detailed ouput
Kinetics	Two reactions show differences	Activation energy is different	Alternative situation presented in which temperature is increased

CHAPTER 4. GENERAL DISCUSSION

This dissertation begins with a study in a CURE that explores the construct of critical thinking and how we measure it. Critical thinking is something that is rarely defined in educational goals even when desired. Study 1 explores a working definition of critical thinking while showing how it can be increased with participation in a CURE. Moreover, a CURE is even more effective in terms of critical thinking gains when it is seen by participants as more authentic. This finding has proven to be of interest because decision-making within a CURE must be framed within the context of providing an authentic experience for the students. This not only contributed to the CURE literature by showing positive effects from a CURE implementation, but contributed to the critical thinking literature as a method for increasing critical thinking as defined by the authors.

Though there were positive gains shown from this study, implementation of the CURE was at a significant cost of instructor time and efforts. Instructors worked many hours to get the program running and maintain the research projects. Reducing this load on instructors was the primary goal of subsequent implementations of this program. With this in mind, the subsequent iterations of the CASPiE method of instruction reduced student research to a single project that they worked on with their groups. Resource requirements were reduced as the research project that was used was operated by USMA faculty, allowing for onsite supervision of the project. Students could further ask questions directly to research faculty in the following years of the program.

The second study in this dissertation turned to a more theoretical lens in its focus. The control-treatment comparison of students revealed deeper-understanding for top-performers in the expansively framed condition. This result was not observed in the lower-performers. This research contributes to the expansive framing literature as well as overall transfer literature in that a possible relationship is explored though causal interpretability is not statistically supported due to small sample sizes. This study, however, was not as taxing on instructing faculty and was more organized for participating students. It was the first study done since the CASPiE method was implemented as the primary laboratory instruction method for second semester chemistry students at USMA.

Together, these studies create a strong case for the use of course-based research in postsecondary educational settings as well as open many threads of future research. Each primary result not only has possible causal mechanisms, but future studies that could compound evidence and make a stronger case for these findings. I will explore these options for each study individually.

First, study 1 shows critical thinking increases based upon authenticity. When students perform authentic activity, they may become more engaged with the material. Student engagement was anecdotally observed in their unique ideas and hypotheses that were developed as well as how students discussed these projects with roommates, friends, and parents. This engagement could have increased student motivation. Motivation in the classroom, though not measured, was observed by students' commitment of time. Cadets at USMA have very limited free time in their schedules and many activities that fill them. They do not have the time allowance that most university students enjoy or devote to extra-curricular involvement. Cadets are on very strict timetables, therefore commitment to any course activity outside of the normal class hours could be viewed as a sign of higher motivation for the project. This was observed by participants in study 1. Cadets involved in the CASPiE program came in to meet research faculty on nights and weekends to collect more data and engage with their various projects. Motivated students pay more attention when they are working on course material, so if the students were more motivated, they would have been more attentive in the course and recognized stimuli from the instruction. These stimuli are then recognized and encoded which is the process of learning as encoding fosters deeper understanding of material. The deeper understanding of inner workings of problem solving allowed them to solve problems on the Critical Thinking Assessment Test and this led to higher scores for students that viewed the activity as more authentic. Further, students that scored high on course material received rewarding feedback and therefore displayed higher self-efficacy and perceived learning (a result observed by study 1).

Each one of these postulated mechanisms are inferred theoretically but do not contain empirical data to support them. Each step of the process opens room for future studies to collect data to support the mechanism. Future studies also could examine other factors that increase critical thinking within the CURE participants. This is clear as the explained variance for the regression models was between 10% and 11% leaving room for plenty of unexplained variance to be defined.

The second study shows a possible link between expansive framing and transfer ability. This link is one that leaves room for much future work. It is my belief that when students are instructed in an expansive manner, they begin to see the content in broader terms. They begin to see that there are uses for the content outside of the classroom or even university. Once they view the content as more applicable, the begin to see a necessity for them to learn it. This necessity causes them to pay attention to stimuli presented to them in the course. These stimuli (as suggested before) are then organized and encoded in a deeper way. This deeper understanding is a fundamental piece of transfer applications as content is appropriately transferred when surface features clue students into retrieval of deeply structured knowledge (Chi & Vanlehn, 2012). This is a possible mechanism for the observed result but still leaves room for future studies to investigate the various components of the mechanism. Larger studies of similar nature also could give more statistical power to observe significant differences on transfer assessments.

In conclusion, this dissertation has presented two studies framed within CURE implementations at the United States Military Academy. They observed both outcomes of the course and possible explanations for those outcomes. Future studies should work to further support and explain the claims made by these results. Further, the mechanisms by which these results were reached leave room for many future studies. The specific details do not yet appear to be clear as to exactly why results were observed in the way that they were, but what does appear clear from both studies is that CUREs appear to be excellent instructional tools to give students unique experiences with many academic benefits.

I would like to acknowledge the Center for Authentic Science Practice in Education and Gabriela Weaver for the instruction on methods and help with implementation of the course-based research curriculum at USMA. Further, I would like to acknowledge Eileen Kowalski, Leon Robert, and other USMA faculty for their hard work and continued support to make the CASPiE pedagogy and instructional methods a part of the chemistry curriculum at USMA. Finally, I would like to acknowledge Joseph Pekny and Eric Dietz for their support of educational research collaborations between Purdue University and USMA.

REFERENCES

REFERENCES

Abraham, M.R., Craolice, M.S., Graves, A.P., Aldhamash, A.H., Kihega, J.G., Gal, J.G., Varghese, V. (1997). The nature and state of general chemistry laboratory courses offered by colleges and universities in the United States. Journal of Chemical Education, 74(5), 591-594.

Ames, B.N. (1979). Identifying environmental chemicals causing mutations and cancer. Science, 204(4393), 587-593.

Auchincloss, L., Laursen, S., Brandchaw, J., Eagan, K., Graham, M., Hanauer, D., Lawrie, G., McLinn, C., Pelaez, N., Rowland, S., Towns, M., Trautmann, N., Varma-Nelson, P., Weston, T., & Dolan, E. (2014). Assessment of course-based undergraduate research experiences: A meeting report. Cell Biology Education – Life Sciences Education, 13, 29-40.

Bangera, G., & Brownell, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. *CBE-Life Sciences Education*, *13*(4), 602-606.

Biggs, J. (2003). Aligning teaching and assessing to course objectives. *Teaching and Learning in Higher Education: New Trends and Innovations*, *2*, 13-17.

Brownell, S.E. & Kloser, M.J. (2015). Toward a conceptual framework for measuring the effectiveness of course-based undergraduate research experiences in undergraduate biology. Studies in Higher Education, 40(3), 525-544.

Bruehl, M., Pan, D., & Ferrer-Vinent, I.J. (2015). Demystifying the chemistry literature: building information literacy in first-year chemistry students through student-centered learning and experiment design. Journal of Chemical Education, 92, 52-57.

Bybee, R. (2000). Teaching science as inquiry. In J. Minstrel & E. H. Van Zee (Eds.), Inquiring into inquiry learning and teaching in science (pp. 20–46). Washington, DC: American Association for the Advancement of Science (AAAS).

Canaria, J., Schoffstall, A.M., Weiss, D.J., Henry, R.M., & Braun-Sand, S.B. (2012). A model for introductory undergraduate research experience. *Journal of Chemical Education*. 89, 1371-1377.

Carmel, J. & Yezierski, E. (2013). Research and teaching. Are we keeping the promise? Investigation of students' critical thinking growth. Journal of College Science Teaching. 42(5), 71-81.

Chase, A.M., Clancy, H.A., Lachance, R.P., Mathison, B.M., Chiu, M.M., & Weaver, G.C. (2016). Improving critical thinking via authenticity: The CASPiE research experience in a military academy chemistry course. *Chemistry Education Research and Practice*. *In press.*

Chi, M. T., & VanLehn, K. A. (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist*, *47*(3), 177-188.

Cosper, S. (2014, December 4). Rotary Kiln Gasification of Solid Wastes for Base Camps. Retrieved August 1, 2016, from https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2211/WP-2211/(language)/eng-US

DebBurman, S.K. (2002). Learning how scientists work: Experiential research projects to promote cell biology learning and scientific process skills. Cell Biology Education, 1, 154-172.

Derry, S.J., Wilsman, M.J., & Hackbarth, A.J. (2007). Using contrasting case activities to deepen teacher understanding of algebraic thinking and teaching. *Mathematical Thinking and Learning,* 9(3), 305-329.

DiStefano, C., Zhu, M., & Mindrila, D. (2009). Understanding and using factor scores: Considerations for the applied researcher. Practical Assessment, Research & Evaluation, 14(20).

Engle, R.A., Lam, D.P., Meyer, X.S., Nix, S.E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist*, 47(3), 215-231.

Engle, R.A., Nguyen, P.D., Mendelson, A. (2011). The influence of framing on transfer: Initial evidence from a tutoring experiment. *Instr. Sci.* 39, 603-628.

Gasper, B. & Gardner, S. (2013). Engaging students in authentic microbiology research in an introductory biology laboratory course is correlated with gains in student understanding of the nature of authentic research and critical thinking. Journal of Microbiology & Biology Education, 14(1), 25-34.

Gasper, B.J., McCreight, J.C., Banschbach, K., Bustion, A., Davis, C., Divecha, R., Donoho, M., Elmore, A.G., Garrison, C.M., Glenn, S., Goeman, D.C., Haby, M., Hooks, T., Korman, A.M., Kowal, J., Kuschke, S., Mellencamp, J.E., Meyer, M., Myers, A.N., Nichols, M.F., Pfeifer, A., Porucznik, A., Qu, X., Ramos-Miller, M., Reed, R., Sagintayev, A., Singel, J.M., Smigh, A., Valle, M.E., Venderley, A., Weber, C.A., Zaffino, A.J., Csonka, L., & Gardner, S.M., (2012). Isolation and preliminary characterization of amino acid substitution mutations that increase the activity of the osmoregulated ProP protein of *salmonella enterica* serovar typhimurium. *DNA Cell Biology.* 31(6), 956-967.

Grover, S., Pea, R. (2016). Designing a blended, middle school computer science course for deeper learning: A design-based research approach. *International Conference of the Learning Sciences.*

Gupta, T., Burke, K.A., Mehta, A., & Greenbowe, T.J., (2015). Impact of guided-inquiry-based instruction with a writing and reflection emphasis on chemistry students' critical thinking abilities. Journal of Chemical Education, 92, 32-38.

Hu, L. & Bentler, P.M. (2009). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling. 6(1), 1-55.

Hoch, M., Russell, C.B., Steffen, D.M., Burgess, J.R. & Weaver, G.C. (2009). Assessment of antioxidant capacities in foods: A research experience for general chemistry students. Journal of Chemical Education. 86(5), 595-597

Kim, K., Sharma, P., Land, S.M. & Furlong, K.P. (2013). Effects of active learning on enhancing student critical thinking in an undergraduate general science course. Innov. High Educ. 38, 223-235.

Kloser, M.J., Brownell, S.E., Shavelson, R.J., Fukami, T. (2013). Effects of a research-based ecology lab course: A study of nonvolunteer achievement, self-confidence, and perception of a lab course purpose. Journal of College Science Teaching, 42(3), 72-81.

Kuo, E., & Wieman, C. E. (2016). Toward instructional design principles: Inducing Faraday's law with contrasting cases. *Physical Review Physics Education Research*, *12*(1), 010128.

Lin, S. (2014). Science and non-science undergraduate students' critical thinking and argumentation performance in reading a science news report. International Journal of Science and Mathematics Education. 12(5), 1023-1046.

Linn, M. C., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Undergraduate research experiences: Impacts and opportunities. Science, 347(6222), 1261757.

Lunetta, V. N. (1998). The school science laboratory: Historical perspectives and centers for contemporary teaching. In B. J. Fraser & K. G. Tobin (Eds.), International handbook of science education. Dordrecht: Kluwer.

Mathison, B. & Holstege, D., (2013). A rapid method to determine sterol, erythrodiol, and uvaol concentrations in olive oil. Journal of Agricultural and Food Chemistry, 61(19), 4506-4513.

Osborne, J. (2014). Teaching critical thinking? New directions in science education. School Science Review, 95(352), 53-62.

Olson, S. & Loucks-Horsley, S. (2000). Inquiry and the national science education standards: A guide for teaching and learning. National Academy Press, Washington, DC.

Pilarz, M. (2013). Implementation of a research-based lab module in a high school chemistry curriculum: A study of classroom dynamics. Doctoral thesis, Purdue University, West Lafayette, IN.

Quitadamo, I.J., Brahler, C.J. & Crouch, G.J. (2009). Peer-led team learning: A prospective method for increasing critical thinking in undergraduate science courses. Science Educator, 18(1), 29-39.

Russell, C. & Weaver, G., (2008). Student perceptions of the purpose and function of the laboratory in science: A grounded theory study. International Journal for the Scholarship of Teaching and Learning, 2(2). Article 9.

Russell, C.B., Weaver, G.C., (2011). A comparative study of traditional, inquiry-based, and research-based laboratory curricula: impacts on understanding of the nature of science. Chemistry Education Research and Practice. 12, 57-67.

Scantlebury K., Li Y., & Woodruff, S.B., (2011). Evaluation of CASPiE: Final report. Oxford, OH: Miami University.

Schwartz, D. L., & Bransford, J. D. (1998). A time for telling. *Cognition and instruction*, *16*(4), 475-5223.

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. *Transfer of learning from a modern multidisciplinary perspective*, 1-51.

Schwartz, D. L., Chase, C. C., & Bransford, J. D. (2012). Resisting overzealous transfer: Coordinating previously successful routines with needs for new learning. *Educational Psychologist*, *47*(3), 204-214.

Schwartz, D. L., Chase, C. C., Oppezzo, M. A., & Chin, D. B. (2011). Practicing versus inventing with contrasting cases: The effects of telling first on learning and transfer. *Journal of Educational Psychology*, *103*(4), 759.

Schwartz, D. L., & Martin, T. (2004). Inventing to prepare for learning: The hidden efficiency of original student production in statistics instruction. *Cognition & Instruction*, *22*, 129-184.

Schwartz, D.L., Tsang, J.M., & Blair, K.P. (2016). *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and how to use them.* New York, NY: W. W. Norton & Company.

Shell, A. (2002). The Thayer method of instruction at the United States Military Academy: A modest history and a modern personal account. *Primus*. 12(1), 27-38.

Snellman, E., Krueger, J. & Unangst, E. (2006). Moving research into the classroom. Journal of College Science Teaching, 35(5), 32-36.

StataCorp. (2015). Stata Statistical Software: Release 14. College Station, TX: StataCorp LP.

Stein, B., Haynes, A., Redding, M., Ennis, T., & Cecil, M. (2007). Assessing critical thinking in stem and beyond. In M. Iskander (Ed.), Innovations in E-learning, Instruction Technology, Assessment and Engineering Education (1 ed., pp. 49-82). New York, NY: Springer-Verlag New York, LLC.

Szteinberg, G. & Weaver, G. (2013). Participants' reflections two and three years after an introductory chemistry course-embedded research experience. Chemistry Education Research and Practice, 14, 23-35.

Uzuntiryaki-Kondakci, E., Capa-Aydin, Y. (2013). Predicting critical thinking skills of university students through metacognitive self-regulation skills and chemistry self-efficacy. Educational Sciences: Theory and Practice. 13(1), 666-670.

Weaver, G.C., Russell, C.B. & Wink, D.J. (2008). Inquiry-based and research-based laboratory pedagogies in undergraduate science. Nature – Chemical Biology, 10(1), 577-580.

Weaver, G.C., Wink, D., Varma-Nelson, P., Lytle, F., Morris, R., Fornes, W., Russell, C., & Boone, W.J., (2006). Developing a new model to provide first and second-year undergraduates with chemistry research experience: Early findings of the center for authentic science practice in education (CASPiE). Chem. Educator, 11, 125-129.

Wink, D. J. & Weaver, G.C. (2008). Evaluation of the center for authentic science practice in education (CASPiE) model of undergraduate research. Workshop linking evidence to promising practices in STEM undergraduate education, Washington, DC, National Research Council, 14 pp.

Wolkow, T.D., Durrenberger, L.T., Maynard, M.A., Harrall, K.K. & Hines, L.M. (2014). A comprehensive faculty, staff, and student training program enhances student perceptions of a course-based research experience at a two-year institution. CBE-Life Sciences Education, 13, 724-737.

Wood, W.B. & Gentile, J.M. (2003). Teaching in a research context. Science. 302(5650), 1510.

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2013	Purdue University – Science Learning through Engineering Design (SLED). Set up and instructed break-out workshop in professional development summer institute.
2012	Purdue University - Organic Chemistry Research: Mechanistic Methodologies in Organic Synthesis with an Emphasis on Utilization of Boron-Based Reagents. Organic synthesis and characterization with moisture-sensitive reactions.

Professional Experience

2016-	Half-Time Research Assistantship as Director of Educational Assessment. Discovery Park - Purdue Homeland Security Institute. Purdue University. West Lafayette, Indiana.
2016-	Quarter-Time Research Assistantship as Consulting Evaluator/Statistician. Department of Curriculum and Instruction. Purdue University. West Lafayette, Indiana.
2015-	Quarter-Time Research Fellowship as the Burton D. Morgan Center for Entrepreneurship Graduate Entrepreneurial Fellow. Discovery Park. Purdue University. West Lafayette, Indiana.
2013-2014	Half-Time Research Assistantship on the Assessment Team. Discovery Park – Discovery Learning Research Center. Purdue University. West Lafayette, Indiana.

Publications

Chase, A., Clancy, H., Lachance, R., Mathison, B., Chiu, M., and Weaver, G. An interdisciplinary course-based undergraduate research experience at the United States Military Academy: linkages between critical thinking and authenticity. *Chemistry Education Research and Practice* **2016** (accepted: Sept. 2016)

Chase, A., Pakhira, D., and Stains, M. Implementing process oriented guided inquiry learning for the first time: adaptations and short-term impacts on students' attitude and performance. *Journal of Chemical Education* **2013** 90(4), 409-416

Scholarly Presentations

2015 Defense Energy Innovation Summit & Showcase (Austin, TX, Nov. 29 – Dec. 1) Poster Presentation: *Purdue SURF: A Summer Research Program for Military Academy Cadets/Midshipmen.* **A. Chase**, J. Pekny, J. Dietz.

2014 Biennial Conference on Chemical Education (Allendale, MI, Aug 3-7). Oral Presentation: *Implementing The CASPiE Course-Based Research Experience at The United States Military Academy: Initial Findings of Critical Thinking Gains and Affective Responses.* A. **Chase**, H. Clancy, G. Weaver.

2014 Course-Based Undergraduate Research Experiences Conference (Cold Springs Harbor National Laboratory, Cold Springs, NY) Poster Presentation: *Implementing the CASPiE Course-Based Research Experience at the United States Military Academy: Research Methodology and Evaluation Procedures.* **A. Chase**, G. Weaver.

2012 American Chemical Society National Meeting (San Diego, CA, March 25–29). Poster Presentation: *Impact of the first-year implementation of process oriented guided inquiry learning in general chemistry and organic chemistry courses.* **A. Chase**, M. Stains.

2011 American Chemical Society Midwest/Great Lakes Regional Meeting (St. Louis, MO, October 14-19). Oral Presentation: *Impact of the first-year implementation of process oriented guided inquiry learning in an organic chemistry course on students' attitudes and learning.* **A. Chase**, M. Stains.

Teaching Experience

Purdue University	Power and Energy (Instructor)
	Intro to Homeland Security (Guest Lecturer)
	General Chemistry for Elementary Ed. Majors (Supervisor)
	General Chemistry for Engineering Majors (Lab and Recitation)
United States Military Academy	Organic Chemistry (Guest Lecturer)
	Advanced General Chemistry II (Guest Lecturer)

University of Nebraska	General Chemistry I (Lab)
	General Chemistry II (Lab)

Technical Skills – Software Proficiency

IBM SPSS

IBM SPSS – Amos

Statistical Analysis System (SAS) Statistical Software

Stata: Data Analysis and Statistical Software

QSR International: NVivo Qualitative Data Analysis Program

Technical Skills – Data Analyses

Hypothesis Testing

Regression/Correlation Analyses

Structural Equation Modeling

Multilevel Modeling/Hierarchical Linear Modeling

Survey Sampling Procedures

Test/Survey Item Construction

Confirmatory Factor Analysis

Longitudinal Modeling

Qualitative Interviewing Techniques

Qualitative Phenomenological Coding/Analysis

Memberships

American Educational Research Association (AERA) Member